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Quarterly Technical Summary

General Research

15 February 1966

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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 November 1965 through 31 January 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

CONTENTS

DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 November 1965 through 31 January 1966 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 November 1965 through 15 February 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2387A	Redirecting the Search Process	U. Neisser A. Stoper†	Brit. J. Psychol. 56, 359 (1965). DDC 628561
2444	Searching Through Word Lists	U. Neisser H.K. Beller†	Brit. J. Psychol. 56, 349 (1965). DDC 628562
2546	Digital Differential Analyzers with Arbitrary Stored Interconnections	P.E. Wood, Jr.	IEEE Trans. Electron. Computers EC-14, 936 (1965)
2555	Reachability of Subspaces	P.L. Falb	IEEE Trans. Automat. Control AC-10, 472 (1965)
2694	On Some New Results in Shot-Noise	O.A.Z. Leneman	Proc. IEEE (Correspondence) 53, 2130 (1965)
MS No.			
1126	Separation of Gyromagnetic from Gyroelectric Optical Effects in Ferromagnets	D.O. Smith	Proc. International Conference on Magnetism, London: The Institute of Physics and the Physical Society (1964)
1128	Static and Dynamic Theory of Magnetic Fine Structure in Thin Films	K.J. Harte	

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2628	On Mean-Square Reconstruction Error	O.A.Z. Leneman J.B. Lewis	Accepted by IEEE Trans. Automat. Control

* Reprints available.

† Author not at Lincoln Laboratory.

Division 2

JA No.

2647	Maximizing the Longitudinal Magneto-Optical Transmission-Scattering from Multilayer Magnetic and Dielectric Films	D. O. Smith	Accepted by Optica Acta
2658	Optical Scattering from Cubic Electro-Optical Films	D. O. Smith	
2662	Content-Addressed Memory Using Magneto- or Electro-Optical Interrogation	D. O. Smith K. J. Harte	Accepted by IEEE Trans. Electron Devices
2674	A Formal Semantics for Computer Languages and Its Applications in a Compiler-Compiler	J. A. Feldman	Accepted by Commun. ACM
2680	On Error Bounds for Jittered Sampling	O. A. Z. Leneman	Accepted by IEEE Trans. Automat. Control
2741	A Note on Reconstruction for Randomly Sampled Data	J. B. Lewis O. A. Z. Leneman	

Meeting Speeches*

MS No.

†1467	Theory of Large-Angle Ripple in Magnetic Films	K. J. Harte	11th Annual Conference on Magnetism and Magnetic Materials, San Francisco, 16-19 November 1965
†1470	A Sensitive Pulsed Magnetoresistive Measurement of Magnetic Film H_k	R. C. Johnston	
†1472	Measured Relaxation Times for the Uniaxial-Anisotropy Spectrum in Nonmagnetostrictive Permalloy Films	D. O. Smith G. P. Weiss K. J. Harte	
1541	Seeing Solid	R. N. Davis J. B. Lewis B. W. White	ILO Symposium on Sensing, Analyzing, and Processing Visual Information, M. I. T., 21 December 1965

*Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

†To be published in the Journal of Applied Physics Supplement.

DIGITAL COMPUTERS
GROUP 23

I. COMPUTER SYSTEMS

A. TX-2 Optical Scanner

Work has resumed on this project. Experiments have been conducted on automatic starting and DC operation of mercury vapor light sources. In addition, a Celco deflection amplifier has been obtained to replace the IT&T circuitry.

B. Typewriter-Keyboard Consoles

A third console has been put on line and components for two additional consoles have been ordered. The trouble experienced when turning power on and off has been eliminated, although APEX is not yet able to cope with the multiple Help Request signals that are generated.

C. Micrologic Assemblies

The V-Memory Multiplexer, Executive Timer Register, Console Number Register, and Console Output Register have been in operation during this entire reporting period with no failures. Integrated circuits are being used in the new Miscellaneous Input Sequence, Calendar, and Thin Film Memory Testers. These new assemblies are being built and installed as rapidly as flat-pack delivery will permit. Approximately ten new integrated-circuit modules are being made available. These include a pulsed flip-flop, a shaft encoder converter, a gate extender, two gated buffers, a half-adder, a parity logic, a Schmitt trigger, and nine-bit register modules.

D. Displays

Three curve-drawing displays (the master and two slaves) are now on line and being used by APEX. The P-12 phosphor has proved useful for viewing, and light pen experiments with it will begin shortly.

E. TX-2 Modifications

Work is continuing on four new memory modules which will replace the vacuum-tube-driven S-Memory. The last of these has been delivered and all are undergoing tests preparatory to the change. An interim Memory Bus system will be used in order to simplify the transition; the final 4×8 bus switch, which will take full advantage of the 2.0-μsec cycle and the increased number of memory modules, will be installed next quarter.

The carry time for addition in the arithmetic element has also been reduced so that add time is now commensurate with a 2.0-μsec memory cycle.

Other new features were also added to the computer to provide new facilities and to improve program speed. A new mode was added to the Memory Snatch input-output channels so that data blocks can be list-structured. This will be of considerable value in graphics display work. The

program trapping features are also being expanded in order to facilitate supervisor and debugging program design.

The Fastrand Drum file memory was replaced by a new model of the same unit. The new unit offers reduced cost, potentially greater reliability, twice the capacity, and lower access time. These features should be reflected in improved APEX system performance.

F. TX-2 Clock Calendar

A digital clock calendar is being built for TX-2 with series 300 integrated logic. The clock calendar register will have a V-Memory location, will be multiplexed, and will contain a coded representation of the time in seconds, minutes, hours, and day of the year.

G. Data-Terminal Connections

The hardware, software, and operating requirements of a low-speed, multiplexed data-terminal sequence for TX-2 are being studied. Initial requirements are for a system which can communicate with other computers via "dialed-up" or leased phone lines at either teletype or 2000-bit/sec rates, or can communicate with nearby operator consoles similar to the Lincoln Writer.

II. CIRCUIT DEVELOPMENT

A. Nanosecond Integrated Circuits

The Philco UHF switching transistor (f_T of 3 to 6 Geps) described in the previous report has been designed into a simple ECL integrated circuit. Five of these circuits connected in a ring had a cycle time of 7.2 nsec or a delay per stage of about 1.2 nsec. Two of these ECL circuits were connected as a flip-flop which could be set and cleared at a rate of about 340 Mcps in a crude test with sine wave triggering. This particular circuit has some undesirable parasitic elements which will be reduced in a new design. A similar design will be incorporated in the development of a three-input parity circuit which will be used as a test vehicle to study performance and to investigate crossover problems.

The UHF transistor design has also been applied to the npn part of the current-mode circuit used in AETU and SPAT. This part of the circuit contains four npn transistors and seven resistors on an 8 × 8-mil chip.

B. Measurements

Many modifications have been made on the probe system used for the study of integrated circuits. A microscope with a 20X objective and a 14-mm working distance is being set up. Commercial probe tips have been gold-plated and special tungsten tips have been drawn to obtain very small points. The goal of this effort is to gain at least some limited probing capability on 0.1-mil geometry.

Design and preliminary layout is being done on a digital printout system which will record transistor and integrated-circuit data on paper tape so that computer manipulation of the data will be possible. This will eliminate manual transcription of the information to cards (our most time-consuming operation) and require less storage space.

III. MAGNETIC FILM ENGINEERING

A. Clean Room

Main air-intake filters for the clean room are now properly installed as indicated by tests with a Sinclair-Phoenix Aerosol Photometer. Similar modifications must be made to a filter in a duct supplying "make-up" air to the chemical hood in the dark room before the room can function at design levels of cleanliness.

B. Fine-Line Etching

Parameters of the photoetch process are being studied to improve the quality and consistency of fine-line etching for both evaporated metals on glass substrates and for much thicker (half-ounce) copper on flexible fiberglass substrates. Areas of study include the effects of collimated ultraviolet light photoexposures, measurement of uniformity of light intensity of various exposure sources, techniques for the application of more uniform layers of photosensitive resists, and a comparison of spray and bath etching.

C. Photography

Parameters of the photographic process are being studied in preparation for producing, under dust-free conditions, contact copies of precision-scribed master fine-line patterns. Areas of study include determination of optimum exposure and development times, appropriate handling procedures to minimize particulate contamination of plates and films, and suitable methods for removing adhered particles. To help achieve these results, the clean room is supplied with filtered (0.45 micron) distilled water for washing plates and films and a filtered (0.45 micron) dry nitrogen line for blowing away adhered particles. The equipment will be capable of processing precision photographic plates, 8 inches wide and up to 22 inches in length.

D. Large-Capacity Memory Digit Circuitry

A two-transistor flip-flop circuit has been developed to perform the functions of decision element or "strobe" for sensed information, buffer storage for this information, and digit driver.

To strobe, the film signal from the sense amplifier (amplitude $\geqslant 0.6$ volt) is gated into one base of the flip-flop and flip-flop power turned on. The final state of the flip-flop depends upon the sign of the sense signal. For information readout or change, each flip-flop may be accessed externally as an element of a flip-flop memory, each long LCM word being broken into appropriate shorter segments. For digit drive, a unipolar pulse is applied to the center tap of the primary of a digit-drive transformer. The ends of the primary are connected through diodes to the flip-flop transistor collectors which serve as a switch to determine drive polarity. The circuit will drive typical digit lines with rise time less than 30 nsec, fall time less than 15 nsec, and variation in amplitude less than 10 percent for 20-percent variation in line resistance.

E. LCM Memory Stack

The semiautomatic pulse tester is being assembled. When completed, it will permit rapid magnetic and position data recording for each word substrate.

The redesigned Memory-Stack structure is now being built. It is to serve as a full-scale prototype.

The problem of copper-permalloy peeling from the glass substrate has been eliminated by using a 300-Å-thick chromium film on the glass which serves as a bonding layer. This coating has no effect on the permalloy magnetic characteristics and can be etched.

Etching quality continues to be marginal. The major problems of excessive undercut, ragged line edges, and inconsistent etching are being intensively investigated. Experiments with scribing the resist, instead of photoexposing it, have been encouraging. This process is highly efficient, since the pads are photoexposed and the scribing is done automatically.

F. LCM Test Results

Because of the large mutual inductance between word lines, word current in one line may induce currents in adjacent lines. Experiments show that with the present configuration, these currents are not seriously large. Direct comparisons of digit lines of 4, 6, and 8 mils wide show that larger signals and wider margins are obtained with lines less than 8 mils wide.

The design of the automatic error-readout system for the tester is completed.

G. Content-Addressed Memory

Films are now being produced with the new masks. With the elimination of those handling procedures which produced scratches, the uniformity within the few planes since tested appears good. The digit and word current margins are also good.

H. Oblique-Incidence Anisotropy

We have observed the new type of oblique-incidence anisotropy discovered by Metzdorf and Wiehl.* It occurs for fast (~100-Å/sec) evaporation rates in nonmagnetostrictive 1500-Å NiFe films for substrate temperatures above 310°C. The easy axis is in the plane of incidence (i. e., radial) rather than normal to it (circumferential) as is the case for the well-known low-temperature oblique-incidence anisotropy. Experimental results for a 17° angle of incidence gave a maximum radial anisotropy following anneal of 3.5 oersteds at 325°C which decreased to 1.0 oersted at 375°C. Vacuum anneal increased the effective radial anisotropy considerably. Films deposited at 300°C, and initially having circumferential anisotropy, changed to radial anisotropy following a 275°C anneal of less than 15 minutes. It is suspected that the radial anisotropy is due to a 111 fiber axis observed by Metzdorf.

I. Saturable Shielding

Experiments using saturable shielding in memory configurations continue. It has been shown that the application of a digit field to a shield saturated in the transverse direction produces an additional transverse field (by reducing the amount of transverse shielding). It was also discovered that by using a shield with both dimensions comparable to the storage area, shielding of both digit and transverse field could be achieved in such a way that the switching threshold became

*Paper to be presented at the International Colloquium on Magnetic Thin Films, Jena, Germany, April 1966.

more favorable for true coincident writing. Moreover, the control of the threshold tolerance could be achieved through control of shield-film geometry, which should be easier to regulate than storage-film magnetic properties.

IV. SYSTEM PROGRAMMING AND APPLICATIONS

A. Conic Display Generator

By using homogeneous mathematics, it appears possible to construct a relatively straightforward generator for display systems which can draw general conic sections. The basic concept is to generate a ramp and its square (a parabola) and then perform a perspective transformation of this parabola. Circles, ellipses, and hyperbolas are all perspective transformations of a parabola. If the standard parabola is represented by the parametric vector $\bar{t} = [t^2, t, 1]$, and H is a 3×3 matrix (the homogeneous transformation), then $\bar{p} = \bar{t}H$ is the position vector $\bar{p} = [x, y, w]$ of some general conic. In order to display this curve, it is required that we now divide by the homogeneous scale factor w. Thus: $X = x/w$, $Y = y/w$, and X and Y can be sent to the deflection amplifier of the scope. Since the divisions and multiplications needed for this operation generally use considerable hardware, it required an inexpensive implementation to make this method attractive.

The design of a homogeneous conic generator is based upon the assumption that a multiplying decoder that produces an output voltage proportional to the product of a 10-bit digital number and a positive reference level can be economically built. It must maintain 0.1-percent accuracy up to about 100 kcps. Since the requirement is only for two-quadrant multiplication (non-negative reference voltage), the decoder design is fairly standard; by utilizing micrologic flip-flop registers, the whole multiplying decoder package may be fairly cheap.

B. VITAL

The TX-2 compiler-compiler, VITAL, is nearing completion as a complete system. It will be one of the most ambitious integrated programming systems in existence. A VITAL user will be able to program in and redefine a great variety of languages, using sophisticated interactive editing, debugging, and input-output facilities at all levels. The VITAL system will be operating in the next reporting period.

COMPUTER COMPONENTS
GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

The status of the improvements in instrumentation discussed in the last report is as follows: (1) the measurement still utilizes a second harmonic magnetoresistive signal, but has been changed to a magnetic configuration which is less sensitive to perturbations from stray fields, sample misalignment, and magnetization ripple than the previously used method; (2) mechanical equipment for doing the study in an ion-pumped vacuum system is nearing completion; (3) the electronic equipment required for digital recording of the data has been ordered and should arrive early in the next quarter; (4) analytical and computer programming studies to develop computer methods of data reduction have been started.

B. Origin of Quadrature Flux in Magnetic Films

The investigation of the origin of quadrature flux (QF) in NiFe films has been completed.[1,2] Field configurations were devised for which the magnetization ripple state was the same for three different directions of the mean magnetization with respect to the switching asteroid. If QF originates in hysteresis of the ripple, QF vs DC field magnitude curves should be the same for all three configurations. This was found to be the case, even for a film with extremely low "dispersion" to which no negative or biaxial anisotropy could be attributed.

C. NiFeCu Films

The investigation of NiFeCu films has been completed.[3] The main conclusions are: (1) the co-evaporation of Cu with NiFe strongly enhances the oblique-incidence effect; (2) Cu also acts to diminish the magnetization-induced anisotropy.

Electron diffraction, electron microscopy, and studies of magnetization vs Cu concentration show that the Cu atoms enter the NiFe lattice without forming a second phase. No unusual physical or crystalline structure was observed. However, not only the strong oblique-incidence enhancement by Cu, but also the fact that $h_w \equiv H_w/H_k$ and α_{90} increase with Cu addition shows that the Cu produces a strong magnetic effect. Furthermore, high Cu films exhibit slow wall motion in the presence of a steady DC field without pronounced Barkhausen jumps. Similar effects have been observed when the Cu was replaced by Al, Sn, Au, Zn or Pb. These facts have led to the speculation that the Cu is concentrated at grain boundaries, thus weakening the inter-grain exchange bond.

II. OPTICS

A. Magneto-Optics

Continued theoretical work on the longitudinal magneto-optical transmission-scattering from multilayer magnetic and dielectric films has resulted in a new, and apparently practical, structure which is predicted to have ~10-percent conversion efficiency.

B. Electro-Optics

1. Optical Phase Shifter

An effort has been started to build the electro-optical phase shifter described in the last report. As a first step, equipment has been assembled to fabricate single crystal films of ZnS by the method described by deKlerk and Kelly.[4]

2. Light Deflector

A study has been started to design a voltage-controlled light deflector. Qualitatively, such a deflector appears to be possible by applying a voltage gradient instead of a constant voltage to the electro-optical phase shifter mentioned above. Detailed calculations, however, have not yet been successful in verifying this proposal.

C. Thermo-Optics

It should be possible to write information into a magnetic film by means of the heating effects of a focused laser beam. In principle, information density of the same order as is possible with ordinary photographic film should be possible in magnetic film, but with the attendant advantage of immediate readout and rewrite capability. A 1-watt CW argon laser has been obtained and experiments are being started.

III. ELECTRON TRANSPORT

A. Hot Electron Attenuation Theory

The problem of determining hot electron lifetimes in solids is complicated because of the fact that many possible scattering mechanisms exist for an injected electron, e.g., phonons, other electrons, impurities, and imperfections. The electron-electron collision mechanism has been studied in some detail by Quinn and Ferrell,[5] Quinn,[6] and Adler.[7] The basic approximation of these authors is an expression relating the imaginary part of the electron self-energy to the dynamic longitudinal dielectric constant of the medium.

The above calculations were all carried out for an interacting electron system at zero temperature. As far as we know, the corresponding generalizations to finite temperature have never been given. We have recently studied this problem using the finite temperature perturbation theory as developed by Luttinger and Ward.[8] We find the generalization of Quinn and Ferrell's result for free interacting electrons to be:

$$\Gamma_{\vec{k}}(\epsilon_{\vec{k}}) = \mathrm{Im}\, G_{\vec{k}}(\epsilon_{\vec{k}} - is)$$

$$= \frac{1}{\Omega} \sum_{\vec{q}} [f^{+}(\epsilon_{\vec{k}-\vec{q}})\, N'(\epsilon_{\vec{k}} - \epsilon_{\vec{k}-\vec{q}}) + f^{-}(\epsilon_{\vec{k}-\vec{q}})\, N(\epsilon_{\vec{k}} - \epsilon_{\vec{k}-\vec{q}})]$$

$$\cdot\, v(\vec{q})\, \mathrm{Im} \frac{1}{K(\vec{q}, \epsilon_{\vec{k}} - \epsilon_{\vec{k}-\vec{q}} - is)} \quad .$$

Here, $G_{\vec{k}}(\epsilon_{\vec{k}} - is)$ is the self-energy function, $f^-(\epsilon) = 1/e^{\beta(\epsilon-\mu)} - 1$ is the Fermi function, $N(\epsilon) = 1/e^{\beta\epsilon} - 1$ is the Bose function, $f^+(\epsilon) = 1 - f^-(\epsilon)$, and $N'(\epsilon) = N(\epsilon) + 1$. Also, in this expression, $v(\vec{q}) = 4\pi e^2/q^2$ is the Fourier transform of the Coulomb potential, and $K(\vec{q}, \epsilon - is)$ is the longitudinal dielectric constant of the system.

In addition, it may be shown that $\Gamma_{\vec{k}}(\epsilon_{\vec{k}})$ is a positive quantity and has the physical interpretation of an inverse lifetime through the relation

$$\frac{1}{\tau_{\vec{k}}} = \frac{2}{\hbar}\,\Gamma_{\vec{k}}(\epsilon_{\vec{k}})$$

where $\tau_{\vec{k}}$ is the lifetime for an injected electron of wavevector $\vec{k}$. Analogous expressions also obtain for the case of band electrons in a solid. These expressions are a little more complicated and will not be given here.

B. Oxidation of Aluminum

The work function measurements of aluminum exposed to oxygen and water have been supplemented by microbalance measurements of the quantity of gas adsorbed. The changes occurring in the monolayer region of exposure have been measured, and the kinetics of dry oxidation have been studied up to a maximum thickness of about 6 Å, beyond which the rate becomes too slow for measurement with this particular technique. Agreement has been found between the oxidation kinetics and the data of Eley and Wilkinson,[9] who explain their results on the basis of a place exchange mechanism originally proposed by Lanyon and Trapnell.[10]

However, comparison of the work function measurements with the oxidation kinetics has made it necessary to modify the place exchange mechanism as being the limiting process of oxide growth. The main reason is that place exchange alone does not account for the observations of work function reversibility plus adsorption irreversibility with pressure changes. A modified model has been postulated in which the rate of growth by place exchange is set approximately equal to the rate adsorption, and both mechanisms together are rate limiting. Good quantitative agreement with the experimental results has been obtained with this model.

C. Effect of Mercury in the Work Function of Gold

Measurement of fresh surface contact potentials between Cu, Ag, Au, and Al, and comparison of these results with the literature have shown a discrepancy of $\approx\frac{1}{2}$ ev from previously published values of the work function, φ_{Au}, of gold. Experiments have been carried out which show that the most likely cause of the discrepancy has been mercury contamination in the previous determinations and that the new value is $\varphi_{Au} = 5.22 \pm 0.05$ ev.

D. Al-Al_2O_3 Triodes

Of the several steps which are known to be necessary to improve the power gain of Al-Al_2O_3 triodes, present work is concentrated on obtaining a high impedance collector of good collection efficiency. To this end, a systematic variation of the plasma oxidation parameters is under way, accompanied by an evaluation of the collection efficiency by means of photoelectric measurements.

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PSYCHOLOGY
GROUP 25

I. MAN-COMPUTER INTERACTION

The APEX executive system, which time-shares the TX-2 eomputer, is now used several hours a day, and a substantial inerease in use is expected when some of thc crucial in-out routines are completed. One of the main purposes of the system was to provide the foundation for an experimental facility that would bc used to study the eomputing services needed by scientists and engineers when they are working on line. An initial facility of this sort is nearing completion.

A. APEX Time-Sharing System

The systcm now handles three consoles, each consisting of a keyboard, a typewriter, and a CRT display. Most of the programming of the TX-2 community is devoted to programs that will run in the APEX environment, and operation of the computer now alternates between the time-sharing mode and the old single-user mode, with time sharing aceounting for an increasing fraction of the schedule. A eoneentrated effort is being devoted to the present deficiencies in the system's input-output facilities, and these defieiencies are expeeted to be removed during the next quarter. APEX will then be able to support nearly all the work now planned for TX-2.

The input-output routines have developed considerably in the last quarter. Routines for all the in-out devices, except the keyboard and the typewriter, are now brought into core memory only when needed; the keyboard routine has assumed its final form, which gives better control over the user's typing and allows unused buffers to go out of eore memory onto the drum. The routines for the photoeleetric paper-tape reader are installed, while those for the Xerox printer are working in a preliminary form.

One of the major remaining dcfieieneies in the in-out faeilities is thc laek of routines for the IBM magnetic-tape units. The subroutines for actually handling the tapes already exist, the overall design has been established, and coding has started on the interpretation of the user's calls. Work will rcsume shortly on thc other major deficiency, a routine for the paper-tape punch.

The drum routines have been changed to take advantage of the larger capacity of the new Fastrand II Drum and also the ehanges in the Memory-Snateh (SNAT) hardware. Thc changes to SNAT allow the executive to read and write on the drum outside the area it normally uses. This will improve communication between the time-sharing modc and the single-user mode and will simplify eommunication between users of time sharing.

The expanded use of the system during the past quarter exposed a number of small bugs and one signifieant flaw in the design. The flaw resulted in the loss to the system of varying amounts of file-memory (i. e., drum) space following a certain class of failures. A revision of the procedurc for logging a user out of the system was required, and substantial program changes were

made. The resulting transients have now subsided, and the file-maintenance portions of the system appear to be operating satisfactorily.

The utility routines that list the names in the APEX directories have been extended to allow a sum-check of each file to be printed and to allow all files to be moved to new locations on the drum. Both developments are part of a continuing effort to simplify troubleshooting and recovery from failures.

B. Experimental Facility for On-Line Computation

One of the main reasons for building the APEX system was to provide the foundation for an experimental computational facility for on-line use by technical personnel. The primary purpose of the facility is to investigate the way in which a scientist or engineer would use a computing service that allowed him to spend more time thinking about his problem than about the mechanics of communicating with the machine.

An attempt to construct an initial, minimal facility which would fulfill that requirement is nearing completion. It was assumed that a scientist or engineer working on the problems that arise in his day-to-day work will usually be more interested in applying existing programs than in writing new ones. The initial system therefore emphasizes convenience in applying programs rather than in writing them.

Convenience in applying existing programs is of course pointless unless the user has an adequate library of programs to apply. The decision was made to concentrate at first on users who are interested in manipulating two-dimensional arrays of numbers – a fairly common type of computation at the Laboratory – and a library of about fifty routines has now been prepared. It includes:

(1) Input and output routines, which are used to put arrays of data into the machine and to print or display results. Of particular interest is a small set of routines that plot graphs on the CRT beside the user's typewriter.

(2) Arithmetic routines, which perform operations such as finding the cosines of all the elements in an array, or dividing each element of one array by the corresponding element of another.

(3) Data-rearrangement routines, which perform operations such as deleting parts of an array or joining two arrays together to produce a new one.

(4) Matrix routines, which treat arrays as matrices and perform the usual operations of matrix arithmetic – e. g., inversion, matrix multiplication, and finding characteristic roots and vectors.

All these routines are now public; they are available to any user of the APEX system. With certain obvious exceptions (e. g., in the input routines), all these programs are employed in the same way: the user simply types the name of the program, the names of the arrays on which he wants it to operate, and the name that he wants to give to the array of results. The machine takes care of the clerical details involved in applying the routine and in filing away the results, or if it is unable to perform the routine, it types a message explaining the difficulty.

An important new program, called the Procedure Builder and Runner, allows the user to string together a series of library routines into a single operation which is in effect a new library routine: the new operation is called by typing its name, the names of the inputs, and the name to be given to the results.

While the Procedure Builder has already proven to be a powerful tool for constructing new operations, there will of course be times when the user will need to perform manipulations that cannot easily be contrived from the basic routines he finds in the library. A rudimentary programming language called Junior is therefore being provided to allow the user, or an assistant, to write a new basic routine. A compiler for the language is being constructed with the help of the VITAL compiler-compiler.*

Although Junior is not ready, and although some features of the graph-plotting routines and of the Procedure Builder and Runner are not working properly, the rest of the initial system is running, and a few scientists and engineers have already used it to solve real problems. The limited experience that has been gained is highly encouraging.

II. HUMAN INFORMATION PROCESSING†

A. Discrimination of Recency

The methods described in previous reports were used to assess the effect of exposure time on the judged recency of pictorial material. On half the trials, the nearer of the two pictures that were to be compared was shown for 0.3 sec and the farther for 2.4 sec; on the other half, the reverse was true. It was found that the apparent recency of a picture was reliably higher when its exposure had been longer. If the exposure time is assumed to influence the clarity of the memory trace, these data agree with earlier findings which suggested that the clarity of the memory trace is one determinant of apparent recency.‡

B. Perceptibility and Memorability

In previous experiments, it had been found that if a subject is presented with two sounds, about $1\frac{1}{2}$ sec apart, and is asked to say whether they are the same or different, his performance is better when the second sound is masked by a white noise than when the first is masked by the same noise. In attempting to discover the reason for the difference, it would probably be illuminating to vary the time interval between the sounds. The sounds used in the previous experiments were about 0.3 sec long; in studying the effect of the time interval, it would be convenient to use shorter sounds, which would have a more precise location in time. The experiment was therefore repeated to see whether the difference between noise first and noise second would persist with shorter sounds, e.g., digits that were spoken by the TX-2 computer and that lasted at most 0.1 sec. A strong difference was observed; so the digits will be used in experiments on the effect of the time interval.

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* See the Group 23 section of this report.

† One of the investigators was a National Institutes of Health postdoctoral fellow.

‡ General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 August 1965), p. 13, DDC 623651.

CONTROL RESEARCH
GROUP 28

I. COMPUTATION CENTER DEVELOPMENT

The Laboratory took a second major step in its program of updating the computer center when it began operation of an IBM 360 Model 65 computer during this quarter. This system is intended to provide parallel operation with the 7094 during conversion of Laboratory programs to the 360 Model 67. As conversion progresses, it will also begin to provide some relief to the heavily scheduled 7094.

Testing of an early batch-processing version of the operating system for the Model 65 is under way. This early version of the system presently operates a restricted subset of the Fortran language. For this reason, there has been limited progress on conversion, and the heavy load on the 7094 persists. It is expected that a full version of Fortran will be available for general use with the operating system early next quarter. Programmers have been prepared for this version by a series of classes given at the Laboratory by IBM instructors. As soon as this full version is able to provide a basic capability similar to that which now exists on the 7094, a major effort will be made to convert all continuing programs.

The IBM 360 Model 40 is performing all peripheral operations, with the exception of plotting and paper-tape input-output. These latter functions are still carried on by the remaining 1401. Early next quarter, an IBM 2701 will be installed to enable the Model 40 to control the plotters and paper-tape reader punch. The interface for this equipment has been constructed and tested at the Laboratory. When it is checked out, the Model 40 will be able to perform all peripheral operations. Work is under way to convert the few administrative programs which now run on the 1401. This will be the final step in phasing out the 1401 systems at the Laboratory.

II. HYBRID COMPUTATIONAL FACILITY

During the past three months, major parts of the Digital Differential Analyzer have been checked for proper operation. Minor modifications to the arithmetic sections are being made as a result of initial tests, and tests of the complete system are now continuing.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the research and development efforts of Division 3 for the period 1 November 1965 through 31 January 1966. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 November 1965 through 15 February 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2451A	Radar Observations of Meteor Deceleration	J.V. Evans	J. Geophys. Res. 71, 171 (1966)
2521A	Radio Echo Studies of Meteors at 68-Centimeter Wavelength	J.V. Evans	J. Geophys. Res. 70, 5395 (1965), DDC 626897
2548	Ionospheric Backscatter Observations at Millstone Hill	J.V. Evans	Planet. Space Sci. 13, 1031 (1965), DDC 616607
2593	Relationship of Geometric Optics and Autocorrelation Approaches to the Analysis of Lunar and Planetary Radar	T. Hagfors	J. Geophys. Res. 71, 379 (1966)
2627	Tenuous Surface Layer on the Moon: Evidence Derived from Radar Observations	T. Hagfors R.A. Brockelman H.H. Danforth L.B. Hanson G.M. Hyde	Science 150, 1153 (1965), DDC 628565
2665	Observations of Polarized OH Emission	S. Weinreb M.L. Meeks J.C. Carter A.H. Barrett† A.E.E. Rogers†	Nature 208, 440 (1965), DDC 626888
2699	Radio Structure of the Galactic Center Region	D. Downes† A. Maxwell† M.L. Meeks	Nature 208, 1189 (1965)
MS-1354	Radar Studies of the Moon	J.V. Evans	Radio Science, NBS J. Res. 69D, 1637 (1965)

UNPUBLISHED REPORTS

Meeting Speech‡

MS No.			
1523	The Haystack Antenna as a Radio Telescope	M.L. Meeks	IEEE, Antennas and Propagation Group, Los Angeles, California, 11 November 1965.

* Reprints available.

† Author not at Lincoln Laboratory.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

SURVEILLANCE TECHNIQUES
GROUP 31

Group 31 maintains and operates the Millstone radar system and the Haystack research facility at the Millstone Hill Field Station. The Group conducts research programs that include the development of satellite observation techniques and studies of the ionosphere and aurorae. Significant programs in radar and radio astronomy are in progress at both Haystack and Millstone. The Group also assists the Space Communications Program.

Of particular interest during this reporting period were joint radar observations of Venus near inferior conjunction. Observations at X-band with Haystack showed an anomalously low cross section (about 1 percent) which could be accounted for either by absorption in the atmosphere of Venus or by a lossy inhomogeneous material on the surface of the planet. Experiments are in progress to determine which of these two possibilities accounts for the low cross section. Concurrent radar observation at L-band with the Millstone radar and at X-band with Haystack gave ranges to the planet that were consistent to within ±1.5 km, thus showing no evidence of X-band scatter from solid particles or droplets extending to high levels in the atmosphere of Venus.

I. OPERATION, MAINTENANCE, AND IMPROVEMENTS

A. Millstone Radar

Venus observations were made one day per week at the start of the reporting period and increased to three days per week during the latter part of the period as the minimum distance to the planet for this orbit was reached. A variety of lunar measurements were also made. The ionospheric backscatter program continued with one 48-hour run per month at 440 Mcps and one 12-hour run per month at 1295 Mcps. Auroral observations were scheduled at a rate of one 4-hour run per week for most of the period but were finally suspended because of poor coincidence between the observations schedule and the occurrence of auroral events. Satellite tracking operations were generally scheduled for one day per week. As in the past, the objects were usually selected on the basis of special interest, either on the part of the NORAD Space Defense Center or the Lincoln Laboratory Space Communications Program. Millstone continued to act as the prime target illuminator in the MITRE/Millstone 3-station satellite interferometer.

The intersite coupling system that links the Millstone and Haystack systems has been expanded to provide the following additional capabilities: (1) operation of both sites from a common standard of time and frequency, (2) simultaneous radar-mode operation of the two sites from a common excitation source, (3) transfer of Haystack planetary radar data to the Millstone data recording system, and (4) real-time pointing of the Haystack antenna by Millstone for satellite tracking.

The 60-foot parabolic antenna was removed from Tower 3 and was replaced with optical tracking equipment by Group 82. Provision has been made to slave the optical system to the Millstone tracker. Initial tests on Echo 1 during a visually observable pass indicated that Millstone tracking was sufficiently accurate for early experiments in the optical surveillance program.

B. Haystack Research Facility

During the first half of the current report period, the Radiometer Box (R Box) operated on the Haystack antenna, while the 100-kw transmitter was made fully operative in the Radar/Communications Box (R/C Box). On 13 December 1965, the R/C Box was installed on the antenna, primarily for radar observations of Venus, and the R Box was moved to the cornucopia horn antenna for flux measurements. These flux measurements have confirmed the efficiency measurements made earlier for the Haystack antenna at 8 and 15.5 Gcps.

Transmitter operation at a 100-kw power level was achieved in the R/C Box using the Varian VA-879 klystron at 7.75 Gcps. Both the klystron amplifiers and the transmitter protective systems are believed to be considerably improved. Approximately 22 hours of operating time were logged at the 100-kw power level. Also, three parametric amplifier channels were put into operation in the R/C Box, with flange temperatures between 35 and 50°K using liquid helium cryogenics. On some planetary measurements, two cooled channels were operated simultaneously for 8-hour periods to provide amplification for two signals with orthogonal polarization.

A passive tracking system was made operational to permit tracking of the CW beacon on LES satellites. The system is based upon beam lobing techniques and utilizes programs in the Univac 490 computer to close the antenna tracking loop.

New regulators were installed on oil-pad units that form the hydrostatic azimuth bearing of the antenna to assure safe interlock operation in the event of bearing oil-pressure loss. Additional personnel protection systems were also installed.

C. Haystack Planetary Radar Development

A new plug-in box for Haystack to be used for planetary radar observations is being equipped with a half-megawatt transmitter and a maser. This box is designated as the Planetary Radar (PR) Box. The design of the electronics progressed to the point that orders have been released for all major subsystem components. The wooden replicas of the klystron transmitter, beam control unit, high-power microwave network, driven components, power and phase monitoring waveguide assemblies, and the maser have been completed. Delivery of the major subcontracted items, the 250-kw klystrons, maser, and beam control unit, is expected late in the next quarter. Evaluation of the performance of microwave components continued in Group 46.

II. SPACE SURVEILLANCE

A. Orbit Upgrading

The basis for a new system of orbit upgrading at Millstone radar will be a real-time version of the existing computer program ESPOD. The new program, or more correctly, set of programs, is to be supplied under contract by TRW Systems. The contract calls for two principal programs: The first program will (1) generate an ephemeris from orbital elements for radar system control, (2) process on-line radar data for the purpose of generating a set of upgraded orbital elements, and (3) provide smoothed observation data for transmission to Space Track. The second program will work on stored observation data for the purpose of generating an upgraded set of orbital elements. The first program is now being integrated into the Millstone system; the second will be delivered during the next quarter.

An effort is under way to extend the range tracking capability of the Millstone radar by coherent processing of radar echoes. This effort requires a computational technique for the rapid determination of power spectra. Various techniques are being compared.

B. Tracking Support

Satellite tracking continued during this quarter with data from 116 priority tracks, representing 41 different objects, being passed to the Space Defense Center. Special operations in support of the Space Communications Program were conducted with orbit searching and tracking of objects associated with the launching of the Lincoln Calibration Sphere (LCS-2) and the Lincoln Experimental Satellites (LES-3 and -4). Also, LCS-1 was tracked for orbit upgrading and cross-section measurement. In conjunction with the LES-3 and -4 tracking, the transtage which placed these objects in orbit was tracked to a range in excess of 14,000 nautical miles, a new record for the Millstone radar. At the request of ARPA, a series of tracks was made on Cosmos 99 (Space Object No. 1817). In addition, a number of tracks were conducted on Molnia I (No. 1324), the Russian Communications Satellite.

III. LUNAR STUDIES

The lunar studies previously conducted under the General Research Program in Radio Physics are now being supported in the main by NASA under Contract NSR 22-009-106. This work will be reported in a separate Quarterly Technical Summary. The work is summarized below.

A. Millstone Observations

Eight periods of lunar observation were scheduled during this reporting period: on three, no measurements were possible because of difficulties in obtaining the required polarization; of the remaining five, three were devoted to examining the depolarizing properties of the lunar surface, and two to the determination of the brightness distribution in the vicinity of the subradar point using an autocorrelation technique.

B. Haystack Observations

No radar observations of the moon were made at Haystack during this reporting period. However, it will soon be possible to operate the Haystack radar in a pulse mode designed for lunar observations. Measurements to determine the angular scattering law at X-band in this fashion can therefore be expected in the next quarter.

Computer programs are being written to support the moon radar mapping program to be carried out at Haystack under contract to NASA. Programs are under development which will (1) point the antenna (via the Univac 490 computer) continuously at a demanded selenographic position at the lunar surface and provide continuous Doppler tracking of the receiver appropriate to that position, (2) take data samples at a rate of up to 100 kcps and perform a spectral analysis to synthesize as many as 128 adjacent filters, each 1 cps wide at as many as 64 delay intervals, and (3) convert the results provided in (2) to a plot of reflectivity vs position over the lunar surface.

IV. PLANETARY STUDIES

A. Millstone Observations

Venus has been observed throughout this reporting period in order to determine its range and velocity. In November, these measurements were made at weekly intervals and the flight time determined to an accuracy of ±50 μsec. In December and January, observations were made twice a week which yielded a delay accuracy of ±10 μsec. These measurements will be continued throughout the next quarter and should provide considerable data from which I. I. Shapiro of Group 62 plans to refine the Astronomical Unit, the orbital elements of Venus and the earth, and the ratio of the earth/moon mass.

Inferior conjunction of Venus occurred on 25 January 1966. For a period of three weeks prior to that date (and a corresponding time thereafter), additional observations were carried out to redetermine the scattering law and also to examine the depolarizing properties of Venus. To date, no major differences from the behavior observed during the 1964 conjunction have been observed.

B. Haystack Observations

1. Venus

X-band observations of Venus were carried out at Haystack in January using the 100-kw R/C Box. These observations show that the radar cross section is indeed anomalously low (~1 percent) as reported previously by Karp, et al.* Spectrum measurements made with a 2-cps resolution indicate that the spectral width of the signals between half-power points is not 75 cps as observed by Karp, et al., but instead approximately 15 cps. This is somewhat larger than one would scale from the L-band measurements at Millstone, but not appreciably so. No evidence has been found for scattering from within the atmosphere of Venus. All the echo energy essentially lies at frequencies between the limits expected for reflection from the limbs. Further, separate ranging measurements carried out at X- and L-band on the same day show that the delay at the two frequencies agrees to within 10 μsec. This, together with the agreement in Doppler shift observed (to within 0.5 cps at X-band), ensures that the X-band echo is from the planetary surface. The low value of the cross section could be accounted for either by a lossy inhomogeneous layered surface or by atmospheric absorption (on Venus). Further measurements and data analysis are in progress to determine which of these two possibilities accounts for the low cross section.

2. Mercury (Plans)

With the current observations of Venus at Haystack, most of the elements of the 100-kw radar system that will be used to observe Mercury this year are being tested. The major additional effort required is in the selection and integration of a suitable delay coding scheme. At present, two contending approaches appear feasible: a phase reversal shift-register sequence, and a swept-frequency modulation. Both approaches appear capable of producing significant

* D. Karp, W. E. Morrow, Jr., and W. B. Smith, Icarus 3, 473 (1964), DDC 613893.

results in real time. The shift-register code requires less additional construction but offers a resolution of only about 64 μsec. With more special-purpose processing prior to digitalization, the swept-frequency modulation promises a resolution of about 20 μsec.

V. ATMOSPHERIC STUDIES

A. Ionosphere

UHF backscatter observations have been carried out for a period of 48 hours each month and L-band observations for 12 hours each month during the report period. The analysis of the results obtained in 1964 is proceeding and seems to confirm the sunspot minimum behavior observed in 1963. Efforts are being made to transfer the data-taking and data-processing operations from the CG-24 computer to the SDS 9300 computer. Thus far, the data processing has been transferred, and the data plotting is now accomplished using the off-line data plotter.

B. Aurora

Radar echoes from the aurora at L-band were obtained on about 30 percent of the days scheduled for observation; however, strong echoes were obtained on only two days. Because of the infrequent auroral activity and the unusually weak radar echoes obtained at the present low point in the sunspot cycle, the scheduling of auroral observations was discontinued early in January. It may be resumed later when there is increased activity.

Some auroral data were obtained during this quarter using the MITRE compressed pulse. However, examination of the data showed that the echoes were too weak to determine the effect of pulse compression in the rejection of auroral clutter. Analysis of the auroral data obtained without pulse compression is continuing, and it is expected that a report on the results will be completed within a few months.

VI. RADIO ASTRONOMY

A. Radiometric Observations

During the current reporting period, the R Box was on the Haystack antenna 43 days and on the cornucopia horn antenna 49 days. Most of the observations on the Haystack antenna were directed toward measurement of the polarization properties of OH emission from the vicinity of the continuum radio source W3. Observations on the cornucopia horn were made to determine the absolute flux of the radio sources Cassiopeia A and Taurus A at 15.5 Gcps. These measurements gave flux values of 269 MKS flux units for Cassiopeia A and 327 MKS flux units for Taurus A. [An MKS flux unit is 10^{-26} watts m^{-2} $(cps)^{-1}$.]

During the previous report period, the OH emission from the vicinity of an HII region, W3, led to detection of polarized spectral-line emission of remarkable brightness using a linear polarization feedhorn. During the current report period, observations were made with a feed equipped to measure right and left circular polarization so that a complete description of the polarization properties can be obtained. These observations show that there is a large circular component in the polarization of all the OH emission features at 1665 Mcps: two out of seven features are 100-percent circularly polarized; five of the seven features are elliptically polarized. In all the features observed, the randomly polarized component is small.

The angular width of the region of OH emission is not resolved by the Haystack antenna beam, and from the response widths measured, it is known to be small compared to 22 minutes of arc, the half-power beamwidth of the Haystack antenna at 1665 Mcps. To unravel the detailed emission mechanism, it is important to determine the angular structure of the emission region. The measured value of the brightness temperature of this region depends on the angular size, since in this case, the observed antenna temperatures are proportional to the product of brightness temperature and angular size. It is therefore very important to study the brightness distribution of the OH emission with higher angular resolution. The next section describes the program by which such information may be obtained.

B. OH-Line Interferometer

An interferometer making use of the Haystack/Millstone antennas at OH-line frequencies can yield a fringe width down to about 1 minute of arc. Such an interferometer system has been planned in detail and construction of components has begun. This experiment is being undertaken with the assistance of the M.I.T. Research Laboratory of Electronics, which has cooperated in previous OH research. Much of the design effort and fabrication of some of the subsystems is being done at RLE. Many of the components have been ordered. Specifications for other specialized items of the subsystem, e.g., parametric amplifiers, have been prepared. One of the large problems to be worked out is a suitable feed for the Millstone 84-foot antenna. The performance of the existing monopulse feed is very poor at OH frequencies. The feasibility of a permanently mounted focal point, dual polarization horn feed is presently being studied by persons in Divisions 4 and 7. Such a feed would be located behind the subreflector of the present Cassegrainian monopulse system and requires that the subreflector be removed during OH observations. The success of this plan depends upon the development of a safe and easy method for handling the subreflector, since it is desirable to minimize the effect of this experiment on Station capabilities for other experiments. The target date for completing the system and initiating the measurements is early summer 1966.

RADAR
DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 November 1965 through 31 January 1966. The major portion of Division 4's activities is devoted to PRESS, Radar Discrimination Technology, BMRS, and Space Communications, which are described in separate reports. The General Research activities in Division 4 are carried out by Group 46, which is engaged in work on Haystack instrumentation, millimeter radar, and microwave component development.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 November 1965 through 15 February 1966

PUBLISHED REPORTS

Technical Report

TR No.				DDC No.
373	Influence of the Earth's Surface on Radar	N.I. Durlach	18 January 1965	627635

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UNPUBLISHED REPORTS

Journal Article

JA No.			
2484	The Packaged and Mounted Diode as a Microwave Circuit	W.J. Getsinger	Accepted by IEEE Trans. Microwave Theory Tech.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects and a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques and receivers for space communications, participation in a millimeter-wavelength program, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar Box

Work continues on the construction of a new plug-in box for the Haystack radar. The box will contain a 500-kw CW transmitter and a maser receiver operating at a frequency of approximately 8 GHz. It is being designed for the optimum use of the Haystack facility as a planetary radar. Orders have been placed for practically all the components to be used within the box. The three major development contracts involve the high-power output klystrons, a grid modulator for the klystrons, and the maser.

A wooden mock-up of the Planetary Radar Box is nearly complete. The mock-up includes the high-power klystrons, waveguide runs, receiver, modulator, coolant lines, and wiring. The framework of the actual box has been completed, and work has started on the skin, flooring, and electrical connector panels. The box should be almost complete by the end of the next quarter.

1. Transmitter

Two developmental 250-kw klystrons (Varian Associates, VA-949 AM) will provide the output power. The tubes will each have two output waveguides and feature a grid for easy modulation. A beam tester is under construction and should be completed very shortly. It is identical to the high-power klystrons, except that the microwave structure is replaced by a block of copper with a small hole. If the results achieved with the beam tester are adequate, the first klystron will be assembled and ready for tests by about 1 March 1966.

Some concern exists about the windows to be employed with the high-power klystrons. Alumina windows have been proposed for this purpose. Calculations have been made of the power-handling ability of windows of various materials and found to be in close agreement with measurements. In particular, calculations and measurements show that half-wavelength block alumina windows will be subject to thermal cracking at a power level only about 20 percent higher than the level in one of the output waveguides. Because high-power windows are often subject to excess thermal stresses due to a multipactor (secondary emission) discharge on the window or a high VSWR in the output waveguide, the safety margin appears too small. Tests will be made of several other kinds of windows, and the use of a window which will give a safety factor of at least two will be encouraged.

The grid modulator is being built by Energy Systems, Inc., and will be of all solid-state construction. It must swing the klystron grids about 10 kv between the off and on conditions. The mechanical and electrical designs have been completed. All parts have been ordered, and construction and testing should be completed during the next quarter.

2. Antenna Feed and Circular Polarizer

High-power testing is in progress and continuous power levels of 180 kw have been obtained prior to breakdown. The possible causes of the breakdown are under investigation. It appears that there is no reason why the horn throat should not withstand 500 kw as required. The breakdown occurs at the junction of the fin-loaded throat and the termination of the central guide walls which initially made poor contact with the gasket that must be used at this point. The problem was corrected by an electrolytic deposition of copper in the area to insure good contact and by soldering the gasket to the face of one of the pieces. These measures increased the breakdown level from about 130 kw to about 180 kw. The problem now appears to have shifted from one of poor contact at the fins to a problem of cleaning the soldered joint so that all traces of flux or other volatile materials are eliminated. This joint can and will be eliminated in the final version of the horn. A Technical Report on the multimode feed is in preparation.

3. Maser

The maser is under development by Microwave Electronics Corporation with Quantum Science Corporation as a subcontractor. They are currently completing tests on a unit very similar to the one we have ordered. During these tests, the stainless steel plate used to mount and align the amplifier structures became slightly magnetic at cryogenic temperatures and was replaced with a copper mount. In order to obtain adequate long-term gain stability, it was necessary to design a special temperature-regulating circuit. The circuit uses a silicon resistor attached to the amplifier structure to sense the temperature and a heating resistor connected through a feedback network. The power supplied to the resistor is also a good measure of the helium level, so that the circuit can be used to replace a more complex scheme previously intended for level indication. These improvements will be incorporated into our maser.

Because of the wide bandwidth of the amplifying structures ($\cong$1000 MHz), it will be necessary to incorporate a narrow-band filter in front of the maser to avoid saturation by stray out-of-band signals. The filter will be cryogenically cooled in the same dewar as the maser. The maser should be completed and tested before the end of the next quarter.

B. L-Band Radiometric Feeds

An excessively high noise temperature has been measured inside the Haystack radome at 1.665 GHz with a Clavin feed. The level constitutes a six-fold increase over that measured with a similar Clavin feed at 7.750 GHz. A possible "hothouse" effect due to the radome has been suggested as the cause of this anomaly. This theory will be checked by using two calibrated horns at 1.665 GHz and at 8 GHz. Two low-phase error "sky" horns of 18-db gain have been procured for this purpose and are now under test. The VSWR of the 8-GHz horn varies between extreme limits of 1.17 to 1.03 over the range from 7.5 to 8.5 GHz. The first side lobe in the

E-plane pattern is 12.5 db below the pattern peak. Similar results are expected for the L-band horn. A report on this work is in preparation.

Parts are now being procured for an L-band radiometric feed which is capable of providing simultaneous outputs of orthogonal linear polarizations or of orthogonal circular polarizations. The feed will be of the dual-polarized focal point type with $1\frac{5}{8}$-inch coaxial feed lines. Two remotely controlled coaxial switches will make it possible to select either the pair of linearly polarized outputs or the pair of circularly polarized outputs. The circularly polarized outputs will be obtained from a $\pi/2$ coaxial hybrid.

C. 15.5-GHz Radiometric Feed

A 15.5-GHz multimode horn feed has been designed and procured for use with the Haystack antenna. The feed does not have a tracking capability; consequently, the TE_{21} and the TM_{21} modes are the only higher order modes involved. These modes modify the E-plane distribution over the aperture of the horn so that equal beamwidths in the principal planes and the high "beam efficiency" associated with the X-band multimode tracking feed are achieved.

Two versions of the throat sections have been built for use with the same pyramidal horn. The first of these results in a linearly polarized horn wherein the higher order modes are generated by a step in the E-plane. This horn can be physically rotated to accept any linear polarization. The second version excites the desired modes with "finned" steps in both planes (quadrature symmetry) to obtain the dual-polarization capability. The horn and throat sections have been delivered and are ready for final tests.

D. Effect of Shock Waves on Ceramic Vacuum Windows

RF arcs have been employed to produce shock waves in WR-112 waveguide for various RF pulse amplitudes and widths. Arcs generated at an overvolted gap between a pair of domed probes in the waveguide have produced shock waves with peak amplitudes linearly dependent upon the RF power level. The peak-shock amplitude occurs after a pulse duration which is inversely proportional to the RF power level. Lengthening the RF pulse beyond this interval does not increase the amplitude of the shock wave. Peak-shock overpressures of 0.028 atm have been measured at 25-kw breakdown levels. Arcs were also induced in full-height waveguide by locating lossy material within the guide. These arcs produced shock overpressures as much as three times greater than those resulting from arcs between domed probes at the same RF power levels.

In order to test the resistance of ceramic windows to shock impact, two $\frac{1}{16}$-inch-thick alumina windows were soldered in WR-112 waveguide and subjected to shock wave overpressures greater than 2 atm without damage.

III. SOLID-STATE AMPLIFIERS

A. X-Band Parametric Amplifiers

The wide-band, X-band parametric amplifier has operated approximately as predicted, i.e., it can be tuned to yield wide bandwidths (200 to 800 MHz) at reasonable values of gain (10 to 20 db). However, under wide-bandwidth operation, the ripple response deviates somewhat from that predicted. In addition, the noise temperature is 250°K rather than the 150°K expected.

No explanation for the excessive noise temperature has yet been verified. Measurements on the signal circuit with no pump power applied to the diode gave results in very close agreement with those predicted by a computer. Similar measurements are now being performed on the idler circuit.

Many of the problems of the wide-band amplifier are related to the broad-banding resonator in the signal circuit. This resonator has been eliminated in a new design now under construction. The new design emphasizes low-noise performance rather than bandwidth.

B. Diode Packages

The purpose of this work is to reduce the values of the parasitic elements of a standard diode package without a change in the external package dimensions. The Micro Optics Company has delivered a number of standard and improved diode packages, both empty and short-circuited. Package capacitance has been reduced about 50 percent by changing the dielectric envelope from alumina to glass; package inductance has been reduced about 25 percent by using two crossed metal straps rather than one to contact the wafer. Effort will be made to further reduce the package inductance and to evaluate the capacitance shunting the diode junction.

C. Diode Measurements

Design has been completed and construction begun on an apparatus for the measurement of varactor diode junction capacitance and resistance by a new technique. The measurements will be made in waveguide at a frequency of 1000 MHz. It is expected that this technique will be capable of somewhat greater accuracy than the present approach. The new scheme will provide an alternative source of measurements and thus permit cross checks of accuracy and independent verification of unusual or unexpected results.

IV. MILLIMETER-WAVELENGTH PROGRAM

A. 8-mm Lunar Radar

The rebuilding of the radar is well under way. The cabling in the penthouse has been reconstituted in a more orderly form. The RF head has been completely laid out and partly assembled. It will use a 10-watt klystron oscillator that is phase-locked to a moderately stable quartz oscillator; the power is scheduled to increase to 50 watts about 1 April. The receiver front end is the same balanced mixer that was used in 1963. This radar will be used for measuring the reflectivity of the moon. In its initial configuration, it may add little or nothing to what was learned in 1963, but it will provide operational experience while the components for the final configuration are still in the procurement stage.

Measurements with a precision spirit level showed that the azimuth axis of the mount is tilted 1.0 minute of arc from the vertical, and that there are a few irregularities in the tilt as the mount scans in azimuth. However, these deviations in the level of the azimuth ring are consistent and can be taken into account in the pointing.

The pointing has been improved by providing closed-loop servo control of the azimuth and elevation rates.

A 35-GHz parametric amplifier and a 1-kw CW amplifier klystron are being procured. The parametric amplifier was built by Laboratory for Electronics under the sponsorship of Wright Air Development Center and is scheduled for early delivery. The klystron will be designed and built by Varian Associates. Since it is to have a 47-db gain, it will be driven directly by a crystal-multiplier chain. The phase-locked oscillator that is an unattractive feature of the present system will be eliminated. The frequency stability of the new system will be sufficient to permit beam-splitting by means of the Doppler effect. Specifications have been drawn up for the new multiplier chain needed to drive the klystron.

B. 8-mm Radiometry

Professor Staelin of M.I.T. is measuring the absorption of millimeter waves in the atmosphere of Venus for evidence of water vapor. This work requires operation at frequencies as low as 19 GHz. To make the antenna usable at this frequency, a larger feed line and a new feed have been installed. The one-way 3-db beamwidth at 23.5 GHz is 5.1 minutes of arc; the pair of largest side lobes are 26 db below the main lobe. If the new feed line can be coupled to the 35-GHz feed without encountering large losses in unwanted modes, it will be used with the radar.

V. VHF MODIFICATION TO TRADEX ERROR HORNS

A scale model of the TRADEX antenna has been procured for an investigation of proposed methods of adding VHF capability to the antenna and also for a general investigation of the radiation properties of the antenna.

The RCA approach to the VHF problem involves the use of four slotted cavity radiators which are placed immediately adjacent to each of the four UHF error horns of the present feed. Two of these slotted cavities have been built to the same scale factor as the model (10.5:1) and tested. The results indicate that the beamwidth in one plane is considerably broadened (to 6.9° in place of the expected 5.5°) and that the efficiency is only 27 percent. Four more scaled versions of the slotted cavities are being built to the final RCA design in order to verify the efficiency figure and to obtain complete pattern data.

A second approach is also being considered as a backup. This method uses the ridges on the UHF error horns to support both the VHF and UHF feeds. Dipoles mounted on the extremities of the ridges yield good matches and patterns (primaries) at both VHF and UHF frequencies. Scale models of this approach have also been built and are being incorporated into the TRADEX model for evaluation.

ENGINEERING
DIVISION 7

INTRODUCTION

During the quarterly period ending 31 January 1966, the Engineering Division has provided mechanical, construction, and control systems engineering for the General Research Program principally at Haystack and Millstone Hills, although some design of hot presses and crystal growth control devices in support of solid state research has taken place.

Outfitting the Planetary Radar Box for use at Haystack Hill and construction activity to provide expanded and safer facilities at the same site were augmented by the overhaul and replacement of servo valves and gauges to improve the antenna drive and control system.

Not only are computer techniques being improved to aid in the structural analysis of antennas and their supports, but preparations are under way to actually rerig the Haystack antenna reflector surface to make it conform more nearly to its design contour.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 June 1964 through 15 February 1966

PUBLISHED REPORTS

Technical Report

TR No.				DDC No.
317	Membrane and Bending Stresses in Shallow, Spherical Shells	F.Y.M. Wan	11 August 1964	607457

Journal Articles

JA No.			
2360A	Thermistor Measures Dielectric Gas Content	E.B. Murphy	Electronics 37, No. 27, 54 (1964)
*2565	A Spectral Radiometer for Re-entry Measurements	R.V. Meyer	Appl. Optics 5, 159 (1966)

* * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
2583	Structural Analysis of the Haystack Antenna	W.R. Fanning	Accepted by J. Struct. Div. (ASCE)
2732	Polystyrene Slab Suffers Thermal Fatigue	E.B. Murphy	Accepted by SPE J.

* Reprints available.

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK

A. Planetary Radar Box

1. Structure

Design and fabrication are continuing on a Planetary Radar (PR) Box and two general purpose (GP-1 and GP-2) boxes.

The welds in the box frames have been x-rayed and show excessive porosity and lack of penetration in certain areas. However, since an inspection and a design review showed stress levels to be well under design levels, the welds have been approved. Design drawings have been completed on the frame supports and the outside closeouts. The three box frames have been RF aligned using the optical fixture at Haystack, and fabrication has begun. Completion of the PR Box closeout is estimated for 1 March 1966.

2. Air Conditioning and Water Cooling

A fan-coil heat exchanger system to be used in cooling the equipment racks, beam modulator package, and the PR Box itself continues in the design stage. Chilled water will be pumped from a ground-level refrigerator to box positions on the antenna and at the test docks. Also, a study is being made to adapt the two existing radar boxes to this system.

The design and mock-up of the cooling-water manifold is 90 percent complete. Several changes have been made during the mock-up to facilitate assembly and for more efficient operation. All the hardware needed for the manifold has been ordered.

3. Microwave Hardware

The design of most of the microwave components has been completed. However, fabrication cannot start until the proper process for the electroforming of these components is decided upon. Most of the commercially available microwave components have been ordered. Dummy components have been made and placed in the mock-up. The mock-up has been used very effectively in determining the location of the waveguide runs and the structure necessary to rigidly support the waveguide and components.

The design of the base ground plane for the beam control unit has been completed and is ready for fabrication.

The design of the RF dummy water loads and associated water-cooling hardware is nearing completion. The added structure needed to support the loads on the exterior of the box has been incorporated into the frame.

4. Site Modifications

Site modifications include changes in the water and service lines from the azimuth wrap to the antenna box position, the addition of an overhead monorail at the inside test dock for tube carriage handling, and the positioning of tube testing and removal equipment at Test Dock No.3.

II. SOLID STATE RESEARCH

A. Hot Press Modifications (Sintering of Powdered Materials)

Improvements in specimen container design and pressure chamber geometry are completed and tests are in progress. A dummy experiment has been performed at which the 1000°C at 100,000-psi pressure requirements were met.

B. Crystal Growth Rate Control Device

Growing crystals under pressure presents the problem of introducing a controlled temperature gradient. A system has been designed in which the pressure bomb can be cooled at variable speeds from 0 to 2 cm per hour for experimentally controlling the temperature gradient.

C. Cooling Cover for Oxide Furnace

A water-cooled dome over an existing furnace permits the melting of oxides under vacuum or controlled atmosphere. Provisions for crystal pulling under the same conditions are incorporated in the design of the cover.

D. Liquid Cell

Gasket design and choice of materials for piston sealing are still being investigated. The rapid increase of the friction component at pressures beyond 300,000 psi is the main concern.

Tests based on a new gasket sealing method appear to be quite promising. Details are now being worked out.

III. LASER RADAR

During the past quarter, the preliminary Laser-Telescope, which consists of a telescope originally designed for the Apollo program and a laser from Applied Energy, Inc., was mounted on the Nike-Ajax pedestal located on the concrete tower at Millstone. This will allow evaluation of the Nike pedestal prior to mounting the final telescope system which is currently under fabrication by Diffraction Limited, Inc.

A drilling template which will locate the mounting holes for the new telescope was fabricated and furnished to Diffraction Limited. Delivery of the new telescope is expected in March 1966.

IV. STRUCTURES RESEARCH

Work has continued on the analysis of paraboloidal shells and the structural stability of radomes. Initial phases of the framed structures analysis and the ill-conditioned matrix study were completed.

A. Paraboloidal Shell Analysis

Chapter IV of the LLAPS (Lincoln Laboratory Analysis of Paraboloidal Shells) User's Manual has been distributed. The design study dealing with the influence of shell behavior on the structural design of large antennas was continued and extended to include sandwich shells such as honeycomb sandwich panels.

B. Framed Structures Analysis

The modifications to the STAIR program and the expansion of the dynamic analysis program are complete and are being used in various design tasks.

C. Ill-Conditioned Matrix Study

The initial phases of this study program have been completed. The results of the study allow one to minimize analysis errors in computer programs; these results are now being utilized.

D. Radome Stability

The radome stability problem has been further defined, and initial analysis efforts were undertaken using existing computer programs. These programs seem adequate for the initial phases of this study.

PHYSICAL PLANT ENGINEERING
GROUP 75

I. HAYSTACK HILL

A. Expansion of Operations Building

The construction plans and specifications for the addition to the Operations Building are now complete and will be sent to the various contractors for preparation of cost proposals. The plans include a 7800-square-foot addition to the Operations Building and a separate 900-square-foot prefabricated metal building that will house the many motor-generator sets now scattered about the site. Construction time for this work is estimated at six months.

B. Fire Detection and Mechanical Failure Alarm System

Fire alarm and mechanical failure alarm systems have been installed in the Haystack facility and are in operation.

The fire alarm system is equipped with heat-sensing thermostats, smoke detectors, and alarm bells, providing adequate coverage throughout the various areas, including the Facilities Building. Sensing devices are interconnected in various areas or "zones," and the location of fire or smoke is indicated on a zone annunciator panel.

A smoke-detector subsystem is connected to the main fire alarm system to indicate smoke in the office area, control room, or computer room by means of sensors in the air conditioning systems. Smoke detectors located in the boiler room and switchgear room are also connected to the subsystem.

Interconnections will be made between the fire alarm system, existing CO_2 systems for the control room underfloor area, antenna tower, and the proposed CO_2 systems for RF boxes. The existing CO_2 systems, including detection and alarm, are now completely independent of the fire alarm system.

The mechanical failure system is connected to failure-sensing devices to provide alarm in the event of any boiler failure, low temperatures in the radome, low radome heating water temperature, low temperatures in the Facilities Building, and low temperatures at the interim fire protection water tank. The mechanical failure panel is mounted alongside the fire alarm panels and is equipped with its own annunciator.

A remote trouble light is installed near the guard desk in the main entrance lobby to indicate a mechanical failure or system malfunction. The mechanical failure panel is equipped with annunciator modules to indicate the actual location and type of system trouble.

C. Dehydrated Compressed Air System

Basic design of the system will be to furnish 50 standard cubic feet per minute (SCFM) of air at a dewpoint of $-10°F$, which will adequately serve the dehydrated compressed air requirements. A supplementary desiccant dryer will have to be used to supply the Phasolver and/or waveguide pressurization. The major equipment will consist of the following:

(1) Packaged compressor-refrigerated dryer unit, air-cooled, 50 SCFM, 15 hp, 240-gallon receiver.

(2) Line filter for removal of vapor, particles, etc.

(3) Piping system of schedule 80 PVC pipe.

D. Tower Access Ladders

1. Installation of Ship's Ladder Inside Haystack Antenna Tower

In order to provide a safer vertical access on the inside of the Haystaek antenna tower, a ship's ladder was taken from the outside storage area and installed in the tower. Steel framing members in the mezzanine floor were cut and reframed and a handrail provided around the stairwell. A gate was installed at the base of the ship's ladder for use with the safety interlock system. The existing vertical ladder was removed and its hatchway covered with grating.

2. Rest Platform and Ladder Modifications for Haystack Antenna Tower

Studies were made of alternative methods for improving safe access on the outside of the Haystack antenna tower. The plan accepted by Group 31 and the Safety Office provides a rest platform halfway up the tower. A second ladder parallel to the existing ladder provides access to the rest platform. In accordance with a recommendation by the Safety Office and with the concurrence of Group 31, a grill guard was provided at each side of the lower (second) ladder. Drawings of this installation have been completed and submitted for fabrieation and installation.

E. Facilities Building

The erection of the 50-foot-wide by 60-foot-long prefabricated metal building is complete. The purchase order for the secondary power distribution and lighting has been awarded. Electrical work should be complete in four weeks.

II. MILLSTONE HILL

A. Air Conditioning Modifications

The existing 40-hp air conditioning compressor has been taken out of service until the electrieal and refrigeration work on the air conditioning system modification is completed.

Interim cooling is to be obtained from a duct connected to the existing return air duct. This temporary system is expected to provide sufficient cooling as long as the outside air temperature is below 40°F.

B. Boresight Antenna

An additional eight-foot reflector is planned for installation on the Millstone test tower which presently supports the six-foot polarization monitor reflector. The new reflector is intended for calibration purposes and will be mounted in a fixed position faeing the Millstone 84-foot antenna. There will be two waveguide or coaxial cable runs from the base of the tower to the reflector feed.

The proposed location of the reflector is such that the additional bending moment will not overstress the tower. The tower manufacturer has stated that the guys have a breaking strength $2\frac{1}{2}$ times the load produced by a 110-mph wind. It was recommended that no additional guys be added unless experience showed objectionable deflections.

The guy anchors for the tower consist of three glacial deposited boulders drilled to receive anchor rods: one is huge; the two smaller anchors were load-tested for the previous design loads produced by wind on the tower supporting a six-foot dish. The analysis indicates a 50 percent increase in guy loads. Thus the smaller anchors will be modified by the addition of reinforced concrete. Contractors are presently preparing quotations for this work.

CONTROL SYSTEMS
GROUP 76

I. NIKE-AJAX OPTICAL MOUNT

At the request of Group 82 (Optics and Infrared), modifications to a Nike-Ajax TTR pedestal were made to permit its slaving to the Millstone radar. These modifications included elimination of the azimuth slip ring assembly and installation of angle transducers in the data boxes to improve slaving accuracy. The Millstone remote target designation transmitter was modified to provide angle transducers compatible with those installed in the data boxes. To permit corrections to pointing angles received from Millstone as well as local control of the Nike-Ajax mount, a handwheel unit was manufactured and installed.

This mount has been moved to the former radar discrimination system test tower at Millstone. Interconnecting wiring has been completed, and preliminary slaving tests with the Millstone radar have been satisfactory.

II. HAYSTACK

Effort is continuing in support of Haystack site antenna operations, including drive-control system development, reflector surface adjustment, and television camera mount design.

A. Hydrostatic Bearing

All work involving the before-and-after test stand and the cleaning of 24 disassembled bearing flow control valves was completed. A large variation in flow control point and valve stickiness was found. Reinstallation of pressure interlock switches on the antenna was completed and the antenna released for operations. Long delivery on individual flow gauges requires their installation at a later date.

B. Servo Control

The "in-house design" servo valve and test fixtures have been completed and installation of the servo valve started on the hydraulic test stand. Initial tests will consist of establishing flow curves vs main spool position, main spool reaction forces contributing to nonlinearity, pilot stage pressure and flow curves, and pilot stage torque motor electrical characteristics.

Design and construction of an inertia stand for closed loop test-stand work incorporating antenna load and oil compressibility effects are in process.

C. Antenna Tracking Loop

Assistance was given in setting up and closing a CW tracking loop for the Haystack antenna. This is the first tracking loop for the antenna and it was closed by use of the Pack Monadnock truck beacon. Successful tracking runs were made on LES-2. The site digital computer provided angle data for acquisition.

D. Main Control Console

A study of console wiring and integration has been started at the site for a finished version of the antenna control console. Control and display hardware has been assembled on five control panels, and back-of-panel wiring has been completed.

E. Reflector Rerigging

The advisability of rerigging the Haystack reflector to provide satisfactory operation at 35 GHz and the problems which might be encountered were studied by the Rerigging Study Committee. Planning for rerigging, including conversations with North American Aviation, Inc., concerning physical access to the reflector surface, is in progress. According to these plans, rerigging is tentatively scheduled for October 1966.

F. TV Mount

Preliminary design of the pointing system for a camera mount to be slaved to the Haystack antenna has been completed. Two television cameras, one of long focal length for extraterrestrial observations and the other of short focal length for cloud surveillance, plus one 35-mm framing camera will be installed on this mount.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 November 1965 through 31 January 1966. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 November 1965 through 15 February 1966

PUBLISHED REPORTS

Journal Articles*

JA No.			
2376	Cyclotron Resonance: (Diamagnetic Resonance)	G. F. Dresselhaus	Encyclopedia of Physics, R. M. Besancon, ed. (Reinhold, New York, 1966)
2410	Diamagnetism	J. B. Goodenough	
2501	Galvano-Thermomagnetic Phenomena and the Figure of Merit in Bismuth. II. Survey of Experimental Data and Calculation of Device Parameters	T. C. Harman J. M. Honig L. M. Jones†	Adv. Energy Conversion 5, 183 (1965), DDC 628559
2520	The Relation of the Electrical Conductivity in Single Crystals of Rhenium Trioxide to the Conductivities of Sr_2MgReO_6 and Na_xWO_3	A. Ferretti D. B. Rogers J. B. Goodenough	J. Phys. Chem. Solids 26, 2007 (1965)
2530	Preparation and Paramagnetism of the Rare Earth Trifluorides	S. Kern P. M. Raccah	J. Phys. Chem. Solids 26, 1625 (1965), DDC 624722
2580	Particle Sizes of Clay Minerals by Small Angle X-Ray Scattering	R. J. Arnott	Am. Mineralogist 50, 1563 (1965)
2597	The Bohr-Sommerfeld Quantization Rule and the Weyl Correspondence	P. N. Argyres	Physics 2, 131 (1965), DDC 626877
2599	High-Field Magnetoabsorption of the Indirect Transition Exciton in Germanium at 1.7°K	J. Halpern B. Lax	J. Phys. Chem. Solids 27, 111 (1966)
2600	Partial Pressure of Se_2 and Optical Density of Selenium Vapor in the Visible and Ultraviolet	R. F. Brebrick	J. Chem. Phys. 43, 3031 (1965), DDC 626893
2609	deHaas-van Alphen Effect in Pyrolytic and Single Crystal Graphite	S. J. Williamson† S. Foner† M. S. Dresselhaus	Phys. Rev. 140, A1429 (1965)

* Reprints available.

† Author not at Lincoln Laboratory.

JA No.

2610	Pressures of Hg and Selenium Over HgSe(c) from Optical Density Measurements	R. F. Brebrick	J. Chem. Phys. 43, 3846 (1965)
2622	Towards a Theory of the Anomalous Thermoelectric Effect in Magnetically Dilute Alloys	L. L. Van Zandt A. W. Overhauser*	Phys. Rev. 141, 583 (1966)
2626	Photocurrent Spectrum and Photoelectron Counts Produced by a Gaseous Laser	C. Freed H. A. Haus*	Phys. Rev. 141, 287 (1966)
2641	Magnetic and Electric Properties of ReO_2: Theoretical	J. B. Goodenough P. Gibart* J. Brenet*	Compt. rend. 261, 2331 (1965)
2642	Solution Regrowth of Planar InSb Laser Structures	I. Melngailis A. R. Calawa	J. Electrochem. Soc. 113, 58 (1966)
2644	The Gunn Effect in Polar Semiconductors	A. G. Foyt A. L. McWhorter	IEEE Trans. Electron Devices ED-13, No. 1 (1966)
2653	Resistance Heated Crystal Puller for Operation at 2000°C	T. B. Reed R. E. Fahey	Rev. Sci. Instr. 37, 59 (1966)
2684	Self-Focusing of Optical Beams	P. L. Kelley	Phys. Rev. Letters 15, 1005 (1965), DDC 628563
2697	Bulk GaAs Microwave Amplifiers	A. G. Foyt T. M. Quist	IEEE Trans. Electron Devices ED-13, No. 1 (1966)
2708	Photoelectron Statistics Produced by a Laser Operating Below the Threshold of Oscillation	C. Freed H. A. Haus*	Phys. Rev. Letters 15, 943 (1965)
2735	Fermi Surface, Magnetic Ordering and Electrical Properties of Rare-Earth Metals	A. J. Freeman* J. O. Dimmock R. E. Watson*	Phys. Rev. Letters 16, 94 (1966)
2743	Evidence for Impurity States Associated with High-Energy Conduction Band Extrema in n-CdTe	A. G. Foyt R. S. Halsted* W. Paul*	Phys. Rev. Letters 16, 55 (1966)

MS No.

843A	Magnetic Ordering in Heisenberg Magnets	T. A. Kaplan	The Molecular Designing of Materials and Devices, A. R. Von Hippel, ed. (M. I. T. Press, Cambridge, 1965)

* Author not at Lincoln Laboratory.

MS No.			
900	Properties Imparted by d Electrons	J. B. Goodenough	The Molecular Designing of Materials and Devices, A. R. Von Hippel, ed. (M. I. T. Press, Cambridge, 1965)
932	Electrons and Holes in Semiconductors	H. J. Zeiger	
1110A	Principles of Injection Lasers	R. H. Rediker	Optical and Electro-Optical Information Processing (M. I. T. Press, Cambridge, 1965)
1339	Amplitude Noise in Gas Lasers Below and Above the Threshold of Oscillation	C. Freed H. A. Haus*	Physics of Quantum Electronics, P. L. Kelley, B. Lax and P. E. Tannenwald, eds. (McGraw-Hill, New York, 1966)
1343	Sum and Difference Frequency Generation in Gases and Liquids	P. N. Butcher* W. H. Kleiner P. L. Kelley H. J. Zeiger	
1396	Magneto-Emission Studies of PbS, PbTe, and PbSe Diode Lasers	J. F. Butler A. R. Calawa	
1397	Laser Emission by Optical Pumping of Semiconductors	R. J. Phelan, Jr.	
1398	Multiple Stimulated Brillouin Scattering in Solids	P. E. Tannenwald	
1399	Plasmon Scattering of Light and Stimulated Emission of Plasmons in Solids	A. L. McWhorter	
1447	Semiconductor Bulk Injection Lasers	I. Melngailis	NEREM Record 7, 240 (1965)

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
2508	Photographic Emulsions as Ion Detectors in Quantitative Mass Spectrography	E. B. Owens	Accepted as Chapter 3 in Mass Spectrometric Analysis of Solids (Elsevier, New York)

* Author not at Lincoln Laboratory.

Division 8

JA No.			
2570	Space-Time Symmetry of Transport Coefficients	W. H. Kleiner	Accepted by Phys. Rev.
2613A	Automatic Potentiometric EDTA and Redox Titrations for Determinations of Stoichiometry	M. C. Gardels J. C. Cornwell	Accepted by Anal. Chem.
2620	A Volumetric Determination of Arsenic and Antimony in Mixed Manganese Arsenide, Antimonide and Phosphide Compounds	E. R. Whipple* D. H. Ridgley	Accepted by Anal. Chim. Acta
2625	Cyclotron Resonance of Piezoelectric Polarons	D. M. Larsen	Accepted by Phys. Rev.
2640	Discussion of "Theory of Nonequilibrium Thermodynamics with Application to the Transport Processes in a Solid" by M. R. El-Saden	J. M. Honig	Accepted by Trans. ASME
2661	Observation of Interband Transitions in Cd_3As_2	E. D. Haidemenakis* J. G. Mavroides M. S. Dresselhaus D. F. Kolesar	Accepted by Solid State Commun.
2667	Four-Probe Device for Accurate Measurement of the Temperature Dependence of Electrical Resistivity on Small, Irregular-Shaped Single Crystals	R. W. Germann D. B. Rogers	Accepted by Rev. Sci. Instr.
2668	On the Polaron Energy Spectrum	D. M. Larsen	Accepted by Phys. Rev.
2670	Remarks on: "An Explanation of the High Cation Vacancy Concentration and p-Type Conductivity in Semiconductors Containing a Multivalent Metal in Its Lowest Valence State"	R. F. Brebrick	Accepted by J. Phys. Chem. Solids
2672	Pseudo-Binary InSb-InTe System	A. J. Strauss M. D. Banus M. C. Finn	Accepted by J. Electrochem. Soc.
2698	Structure of Equations Specifying Operating Characteristics of Energy Converters Constructed of Anisotropic Materials	J. M. Honig T. C. Harman	Accepted by Adv. Energy Conversion

* Author not at Lincoln Laboratory.

JA No.			
2731	Comparative Data on CdS Transducers from 14 Mc/s to 70 Gc/s	R. Weber	Accepted by Proc. IEEE
2736	The Augmented Plane Wave Method and the Electronic Properties of Rare-Earth Metals	A. J. Freeman* J. O. Dimmock R. E. Watson*	Accepted as chapter in Theory of Atoms, Molecules and Solids (Academic Press, New York)
2757	Electron Beam Pumped Lasers of CdSe and CdS	C. E. Hurwitz	Accepted by Appl. Phys. Letters

Meeting Speeches†

MS No.			
1036F	The Band Structure of Semimetals from Magnetoreflection Experiments	M. S. Dresselhaus	Colloquium, Tufts University, 19 November 1965
1036G-1	Magnetoreflection Studies in Semimetals	M. S. Dresselhaus	Colloquium, University of Utah, 16 December 1965; Colloquium, University of California, 17 December 1965; Seminar, Ford Motor Company Scientific Laboratory, Dearborn, Michigan, 10 January 1966
1243I-J	Recent Advances in Semiconductor Lasers	R. H. Rediker	Seminar, National Research Laboratory, Washington, D. C., 6 December 1965; Seminar, Purdue University, 17 December 1965
1415	Designing of Multi-Region Pressure Vessels Using Maximum Shear Theory	A. R. Leyenaar J. A. Kafalas	ASME Symposium, Chicago, Illinois, 7 November 1965
1447A	Semiconductor Bulk Injection Lasers	I. Melngailis	ILO Symposium, M. I. T., 14 December 1965
1528	Transferred Electron Effects in n-GaAs	A. G. Foyt	ILO Symposium, M. I. T., 14 December 1965
1459	Ferromagnetism in $CdCr_2Se_4$ and $CdCr_2S_4$	N. Menyuk K. Dwight R. J. Arnott A. Wold*	11th Annual Conference on Magnetism and Magnetic Materials, San Francisco, California, 16-19 November 1965

* Author not at Lincoln Laboratory.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Division 8

MS No.			
1463	Reduced Manganese Moment in Manganese Chromite	K. Dwight N. Menyuk J. Feinleib A. Wold*	11th Annual Conference on Magnetism and Magnetic Materials, San Francisco, California, 16-19 November 1965
1464	Single Crystal Growth and Properties of the Perovskites $LaVO_3$ and YVO_3	D. B. Rogers A. Ferretti D. H. Ridgley R. J. Arnott J. B. Goodenough	
1466	Electronic Band Structure, Fermi Surface and Magnetic Properties of Palladium Metal	A. J. Freeman* J. O. Dimmock A. M. Furdyna*	
1474	Temperature Variation of the Spin-Wave Dispersion Relation	R. Weber P. E. Tannenwald	
1475	A Covalency Criterion for Localized vs Collective Electrons in Oxides with the Perovskite Structure	J. B. Goodenough	
1477	Crystallographic Study of Several Chromium Spinels	P. M. Raccah R. J. Bouchard* A. Wold*	
1466A	Electronic Band Structure, Fermi Surface and Magnetic Properties of Palladium Metal	A. J. Freeman* J. O. Dimmock A. M. Furdyna*	International Symposium on Quantum Theory of Atoms and Molecules and Solid State Physics, Sanibel Island, Florida, 19-22 January 1966
1517A	The Symmetry of Hartree-Fock Ground States	T. A. Kaplan W. H. Kleiner	
1475B	A Covalency Criterion for Ligand-Field vs Band Electrons in Oxides with the Perovskite Structure	J. B. Goodenough	Seminar, Brown University, 10 December 1965
1486	Quantitative Evaluation of Mass Spectra of Solids	E. B. Owens	Eastern Analytical Symposium, New York, 19 November 1965
1492B	The Gunn Effect	A. L. McWhorter	Colloquium, Center for Materials Science and Engineering, M. I. T., 19 November 1965
1492C	Transferred Electron Effects in Polar Semiconductors	A. G. Foyt A. L. McWhorter	IEEE, Electron Devices Meeting, Waltham, Massachusetts, 20 January 1966

* Author not at Lincoln Laboratory.

MS No.			
1494	Millimeter Wave Phonon Generation, Propagation and Attenuation	P. E. Tannenwald J. B. Thaxter	Ultrasonics Symposium, Boston, 1-4 December 1965
1532	9 Gc Magnetoacoustic Measurements on InSb	K. W. Nill A. L. McWhorter	
1497A	Time Inversion and Transport Coefficients for Magnetic Crystals	W. H. Kleiner	Seminar, Watertown Arsenal, Watertown, Massachusetts, 22 November 1965
1509A	Electrical Properties of Metal Oxides	J. M. Honig	Colloquium, Pennsylvania State University, 14 January 1966
1512	Fourier Expansion for Energy Bands in a Periodic Solid	G. F. Dresselhaus M. S. Dresselhaus	American Physical Society, Los Angeles, California, 20-22 December 1965
1512A	Fourier Expansion for Energy Bands in a Periodic Solid	G. F. Dresselhaus	Colloquium, University of California, 17 December 1965
1529	Electron Recombination in Laser-Produced Hydrogen Plasma	M. M. Litvak	Seminar, M. I. T., 19 November 1965
1530	Stimulated Raman Scattering and Beam Trapping	H. J. Zeiger	Colloquium, Yeshiva University, New York, 18 November 1965; Colloquium, Westinghouse Electric Company, Pittsburgh, Pennsylvania, 16 December 1965
1531	Light Scattering from Spin Fluctuations in Ferromagnets	M. M. Litvak H. J. Zeiger	
1534	Refractive-Index Changes in Absorbing Media by a Pulsed Laser Beam	P. R. Longaker M. M. Litvak	
1535	High Resolution Magneto-spectroscopy of Graphite Using an Infrared Laser Source	P. R. Schroeder* A. Javan* M. S. Dresselhaus J. G. Mavroides	American Physical Society, New York, 26-29 January 1966
1536	Magnetoreflection in Bismuth	M. S. Maltz M. S. Dresselhaus	
1565	The Magnon Dispersion Relation from Spin-Wave Resonance	P. E. Tannenwald	

* Author not at Lincoln Laboratory.

Division 8

MS No.			
1582	Electron Density Measurements from Stark Linewidths in an Argon Laser	R. J. Carbone M. M. Litvak	American Physical Society, New York, 26-29 January 1966
1540	Calculations of Electronic Energy Bands in Solids	J. O. Dimmock	Colloquium, University of Massachusetts, 22 November 1965
1544	Theory of Electromagnetic Field Measurement and Photoelectron Counting	P. L. Kelley	Seminar, Yale University, 3 December 1965
1545A,B	Light Beam Self-Focusing in Nonlinear Media	P. L. Kelley	Seminar, Colorado State University, 8 December 1965; Seminar, Special Weapons Laboratory, Kirtland Air Force Base, Albuquerque, New Mexico, 9-10 December 1965
1556	Structural and Electronic Aspects of the Beta-Tungsten Structure Compounds Nb_3Sn, Nb_3Al and Nb_3Sb as Applied to Superconductivity	H. C. Gatos F. J. Bachner	ILO Symposium, M. I. T., 19 January 1966
1574	Amplification and Gunn Oscillation in "Two-Valley" Semiconductors	A. G. Foyt	International Solid-State Circuits Conference, Philadelphia, Pennsylvania, 10 February 1966
1593	CW Amplification and Gunn Oscillation in GaAs	T. M. Quist A. G. Foyt	IEEE, Active Microwave Effects in Bulk Semiconductors Conference, New York, 3-4 February 1966
1597	Admittance of GaAs Transferred-Electron Amplifier	A. L. McWhorter	
1595	Interband Oscillatory Magneto-Optical Absorption and Faraday Rotation in Semiconductors	J. Halpern	Seminar, Lowell Technological Institute, 9 February 1966

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Laser action has been obtained at ~6900 Å in the red and ~4900 Å in the green from crystals of CdSe and CdS, respectively, bombarded by a beam of fast electrons. Mode structure has been observed in the laser spectra of both these materials, and the wavelength separation between the modes agrees very well with that calculated for the Fabry-Perot mode spacing using the known values for the refractive indices and their dispersion. In both materials, the beam current at the threshold for lasing did not change significantly between nitrogen and helium temperatures. For CdSe, the threshold current density varied from 1.5 A/cm^2 at 20 keV (the lowest electron energy at which lasing could be observed) to 0.2 A/cm^2 at 75 keV (the highest electron energy used), while for CdS, the corresponding values of threshold current were about a factor of five higher. The intensity in all samples saturated at high currents, presumably because of heating – e.g., for 50-keV electrons at about 1.6 A/cm^2 in CdSe, and 6.5 A/cm^2 in CdS. The current level at which saturation occurred increased somewhat with increasing beam voltage. For CdSe at 50 keV, a peak output power of 16 watts at 6850 Å at helium temperature and 10 watts at 6915 Å at nitrogen temperature was measured, corresponding to overall power efficiencies of 8 and 5 percent, respectively. The observed power efficiencies in CdS were considerably lower, i.e., 0.7 percent at helium temperature and 0.3 percent at nitrogen temperature, corresponding to peak optical powers of 10 watts at 4910 Å and 4 watts at 4950 Å, respectively, with a 70-keV beam. Since there is some backscattering of the incident electrons, and the laser emission occurred in only a few small filaments, the local efficiency is presumably even higher in both materials.

Laser action has been obtained at 8300 Å from bulk GaAs pumped with radiation at 7900 Å from a $Ga(As_{0.94}P_{0.06})$ diode laser. Potentially, this technique should be very efficient in the conversion of pump power to laser radiation. The resulting decrease in heat dissipation (compared to inefficient pumping schemes) may enable the design of high-power output stages for semiconductor laser transmitters.

The resistivity of several samples of n-CdTe has been found to increase with hydrostatic pressure by factors of greater than 10^4 between 1 and 28,000 kG/cm^2 at room temperature. This change in resistivity with pressure is too large to be explained either in terms of an increase in average electron mass [either in the (000) minimum or because of electron transfer to higher mass minima] or in terms of deionization into hydrogenic or deep-lying impurities. The pressure coefficient at high pressure of 12.6×10^{-6} $eV/kG\text{-}cm^{-2}$ is very close to the pressure dependence for the separation of the (000) and (100) band minima, and suggests the interpretation of these results in terms of deionization into an impurity level associated with the higher lying (100) conduction band minimum.

II. OPTICAL TECHNIQUES AND DEVICES

Measurements of the infrared radiation emitted by GaAs in the 8300 to 9000 Å spectral region when bombarded by a high-power density electron beam suggest that this compound has potential

as an intense, high-speed, high-resolution phosphor. In order to evaluate this potential, some of the cathodoluminescence characteristics of GaAs are compared to those of the P-11 phosphor. The upper limit of emission intensity that can be expected from GaAs is examined.

The search for a material that would be suitable as a coherent heterodyne detector for the 10.6-μ CO_2 laser radiation has led to a study of Mn-doped GaAs. Unfortunately, the extremely short lifetime ($\sim 10^{-13}$ sec) of the excited Mn acceptor level makes this material far more sensitive as a thermistor detector than as a photoconductor of high speed.

Experiments are reported which determine the probability distribution of the photoelectron counts for a photomultiplier illuminated by a laser slightly below or above the threshold of oscillation.

III. MATERIALS RESEARCH

In order to check the validity of x-ray scattering theory for broad-band semiconductors, the x-ray diffraction of powdered ZnSe has been studied in detail. For a number of weak lines, there are very large discrepancies between the calculated and observed intensities. This result supports the contention that neglect of overlap terms is an important source of error in the theoretical calculations.

The investigation of the transport properties of Ti_2O_3 has been continued by measuring the resistivity and Hall coefficient of single crystals containing low concentrations of nitrogen as the principal impurity. At 4.2°K, the magnetoresistance is directly proportional to the square of the magnetic field up to 170 kG, the highest field employed. The experimental results are consistent with a previously proposed model according to which mixed conduction occurs at 4.2°K, whereas hole conduction takes place at 77° and 273°K.

Optical absorption and EPR measurements have been made on electron-irradiated ruby in order to determine why the cathodoluminescence of ruby saturates and then decreases as the exciting electron beam current is increased. Preliminary results indicate that under irradiation, the reaction $2Cr^{+3} \rightleftarrows Cr^{+2} + Cr^{+4}$ is forced to the right. This could account for the decrease in cathodoluminescence, since neither Cr^{+2} nor Cr^{+4} fluoresces, and it appears that Cr^{+4} quenches the fluorescence of Cr^{+3}.

The outer-electron configuration for α-iron has been determined from the magnetization, g-factor, and symmetries of electron- and spin-density form factors. Lack of complete magnetization of the 3d bands, together with a knowledge of the magnetic ordering in Cr, CrMn, and α-iron, provides information about the nature of electron-electron interactions within a band as a function of the number of electrons in the band. This information is consistent with evidence from several oxides with the perovskite structure.

IV. PHYSICS OF SOLIDS

The study of the room-temperature reflectivity of ReO_3 is continuing. Kramers-Kronig analyses have yielded the real and imaginary parts of the dielectric constant, the effective number of electrons, and the loss function.

The investigation of the layer compound GaSe has been extended. The magnetoabsorption spectrum in the Voigt configuration was found to be isotropic for the magnetic field in the c-plane and radiation along the c-axis. Absorption measurements in crossed electric and magnetic

fields have been initiated. Electroluminescence, as well as magnetic effects on the electroluminescence, has been observed.

Two series of magnetoreflection oscillations have been observed in HgTe, corresponding to two sets of transitions; these results are consistent with a gray tin-like band structure for HgTe.

An extension of the previous magnetoreflection studies in bismuth has not only corroborated the former work but has also revealed additional structure; in particular, a new series of oscillations has been observed with an energy gap $E_g = 0.169$ eV which corresponds to one of the gaps reported by Esaki from electron tunneling experiments.

In collaboration with Professor A. Javan of the M.I.T. Physics Department, the low quantum number interband Landau level transitions in graphite are being studied with a high-resolution magnetospectrometer using a neon gas laser source. Substantial improvement has been achieved over conventional sources in resolution, line shape, and signal-to-noise ratio.

A best fit of the experimental derivative of the microwave surface magnetoabsorption at 70 GHz in p-type PbSe with a classical skin effect theory, including a finite relaxation time, has been carried out. The values of transverse effective mass $m_t = (0.0465 \pm 0.0015)\, m_o$ and anisotropy ratio $K \equiv m_\ell/m_t = 1.8 \pm 0.2$ required for this fit are in satisfactory agreement with the results of Shubnikov-de Haas measurements.

The energy band structure of TiO in the tight-binding theory has been used in an interpolation scheme to approximate the energy bands determined by APW calculations.

The Fermi surface of thulium metal has been determined from a nonrelativistic APW energy band calculation. The computed Fermi surface allows an explanation of the c-axis resistivity anomaly observed in the heavy rare-earth metals at the onset of long range periodic magnetic order.

A Brillouin-Wigner perturbation calculation and a variational calculation have been made for the energy of the $n = 1$ Landau level of a polaron in a magnetic field. The calculations show that as the magnetic field increases, the energy deviates markedly from the usual linear behavior with H and approaches a limiting value.

Measurements of the temperature dependence of 70-GHz acoustic waves in quartz have now been extended to include transverse waves. The T^4 dependence which was previously found for the longitudinal waves is obtained also for the transverse mode, down to 10°K.

Comparative data have been obtained by pulse echo techniques of the performance of insulating piezoelectric CdS film transducers relative to other forms of acoustic excitation in the frequency range from 14 MHz to 70 GHz. The CdS transducers have superior insertion loss characteristics over other common modes of excitation up to 9 GHz, comparable characteristics at 24 GHz, and poorer efficiencies at 70 GHz (on z-cut quartz).

A calculation has been initiated for the classical ground spin state of a magnetic spinel with nonmagnetic ions on the A-sites. Examples of this case are ferromagnetic $CdCr_2Se_4$ and antiferromagnetic $ZnCr_2Se_4$. Magnetic resonance measurements at X-band have begun on the ferromagnetic chalcogenides whose DC magnetic properties had previously been investigated. First results have been obtained in polycrystalline $CdCr_2S_4$ on the line width and g-factor as a function of temperature over the ferromagnetic region as well as the paramagnetic region.

Relations have been obtained between the coefficients of higher-order temperature-dependent terms in the spin-wave dispersion relations. Explicit expressions for these coefficients have been obtained for the case of a Heisenberg model.

Two recent theories of the symmetry restrictions on transport coefficients for magnetic materials have been compared, and it has been shown that one of these is inconsistent with the existence of the anomalous Hall effect.

High-power ruby laser scattering experiments in quartz have been extended to low temperatures. Compared with room temperature, the stimulated Brillouin threshold is only slightly lower, while there is a significant reduction in the stimulated Raman threshold. A number of combination lines belonging to different vibrational modes of the quartz lattice have been observed.

Incoherent second harmonic scattering of ruby laser light in water has been studied as the temperature is lowered toward the freezing point. The scattering increases roughly linearly with decreasing temperature below room temperature.

Possible origins of the nonlinear dependence of index of refraction on field strength, which can give rise to self-focusing or beam-trapping effects, continue to be investigated. It is pointed out that close to an atomic resonance, the real part of the susceptibility can be a strong function of power level because of saturation.

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13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 November 1965 through 31 January 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory

14. KEY WORDS

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